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J. C. Brannen

REPORTS

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ON THE

COMBUSTIBLE QUALITIES

OF THE

Semi-Anthracites

OF THE

erbes's Run Coal Fields,

IN THE

SHAMOKIN BASIN, OF PENNSYLVANIA.

BY

AUGUSTUS A. HAYES, M. D.
PROF. HENRY D. ROGERS.

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REPORT OF EXPERIMENTS

ON THE

EVAPORATIVE POWER

OF THE

ZERBE'S RUN SEMI-ANTHRACITES,

BY

AUGUSTUS A. HAYES, M. D.

REPORT.

THIS Coal, from its lamellar structure and dark color, resembles some of the most compact bituminous coals, but is more brilliant. In breaking, it does not exhibit a tendency to the conchoidal fracture, but divides at natural joints and fissures. No slaty admixture appears, the coal being remarkably clear. Its Sp. Gr. varies from 1.3575, 1.3820 to 1.5090 the highest, 1.3820 being a mean. After exposure for some days to rain and snow, and still wet, this coal loses by drying at 84° F. 4 parts in 100 parts, representing the maximum of water absorbed and adhering to the fragments. In the ordinary state of dryness, 100 parts of this coal lose after careful desiccation at 212° F. 0.61. When heated to 312° there is a slight emission of odor, and 2.33 parts are lost by 100 parts. Beyond this point of temperature, perfectly inflammable gases are disengaged, weighing 7.31 parts. Various samples thus treated, lost in all 9.18 to 9.64 parts of volatile matter. In trials on numerous samples, no sulphur, nor compound of sulphur, was volatilized. A trace of sulphuric acid is present in the ashes, as sulphate of lime. Much of the coal presents a highly iridescent tarnish, which is caused by a thin investing film of crenate or humate of lime; resulting from infiltration of water from the soil.

When masses of this coal are heated till the inflammable parts are disengaged, they divide into fragments slightly

adhering, of small size. The lines of fracture are not preserved, but the fragments present an assemblage of irregular forms, having curved surfaces. In some cases there have been concentric layers on spheriodal centres very brilliant, and true anthracite carbon in the arrangement of the constituent particles.

The opinion of Prof. Rogers corresponded with my own, in the conclusion that the actual economical value of this coal, could best be learned by burning it under varied circumstances. But for the more immediate solution of the question of its practical value, we considered that a comparison of its power in generating steam, with that of a well known and highly prized variety of dry anthracite, would afford us the most direct means. As this coal differs from the dry anthracites, in containing 7 per cent. of combustible gases, and divides by the influence of heat into fragments which under some conditions of burning might essentially affect its economical expenditure, it was deemed important to investigate the two influences separately. It was therefore determined that the coals used for comparison, should be burned by a current of air forced in contact with the fuel; a measure which insured the combustion of about the same corresponding weights of the two fuels, in the lapse of the same time. Confining our attention to the more pertinent question of value, it appeared to us that a series of comparative trials, corrected for obvious disturbances by repetition, would give us in the shortest time, important conclusions, in this connection. We therefore used an apparatus consisting of four steam boilers, each about 30 inches in diameter and 36 feet long, heated by one fire, and so arranged as to be suited especially to the combustion of anthracite coal. The grate of 36 square feet was composed of bars having 3-4 inch spaces, the boilers presented about 600 feet of surface to the heated gases. The steam generated was used under nearly like pressure of 60 to 75 lbs. on a square inch. Careful attention was directed to the condition of the pumps supplying

the water to the boilers, and no leaks nor any disarrangement were allowed during the trials. By means of a metal-lined cistern, provided with an overflow pipe, the water was accurately measured; communication with the pumps was then opened, and the contents as required were continuously pumped into the boilers, till the cistern was exhausted. The pumps were then shut off, the cistern refilled, and the time required for the exhaustion of the first cistern noted, as also that of the working of the pumps on the second cistern. The weight of water contained in the cistern, was 10.587 1·2 lbs., requiring under the most rapid evaporation to be filled six times in 24 hours.

In the comparisons the water in the boilers was previously heated till the tension of the steam was 60 lbs.; it was then increased to the normal level, coal from a weighed quantity thrown on the fire, and the pumps set at work on a full cistern of water. At the close of the experiment the water was allowed to fall to the normal level and pressure, while the condition of the fire was made as nearly as possible like that at the commencement. To avoid irregularities which attended the first results of trials, from the daily increasing heat of the masonry flues, alternations of experiments on each kind of coal were made, till an average was obtained. In determining the weights of the earthy parts, we divided them into two kinds, melted or slaggy portions, and ashes mixed with small portions of coal, and they were weighed separately. These determinations were made on the considerable weights of each fuel, necessary for a week's consumption, to include dirt and dust from breakage and other sources, and may be considered as the largest production in actual continuous consumption. This drawback on the value of any fuel, presents two points which are alluded to above; the formation of semi-fused slags, or cinders, and the fine ashes. When fuel is rapidly burned by a forced blast of air, the proportion of the melted portion of the earthy part of the fuel is much increased; the smallest production of clinker follows the slow com-

bustion of any fuel. The coal from Zerbe's Run is a white ash coal, and its ash is of the most infusible kind; yet in fires of great intensity, imperfect fusion of a part of this earthy matter takes place. During its slow combustion on a grate having narrow openings, the ash forms no aggregations whatever, and contains less of unburnt carbon, than that from any known kind of anthracite.

In the table which follows we have brought under one view the results of careful trials and comparisons. In making use of an arrangement of boilers, adapted to the combustion of dry anthracite, we made no reference to a special fitting of the grate, for insuring an equal distribution of the air, and by diminishing the spaces, reducing the volume of unburnt air, which necessarily passes when dry anthracites are burnt. As the inflammable part of this coal is disengaged at 325 degrees, and being unmixed with aqueous vapor, burns at a moderately high temperature, without smoke, the inference is highly probable, that this portion of the weight of the coal will afford a much higher temperature, or vaporize more water, than an equal weight of dry carbon. Theoretically speaking, therefore, such coal considered free from ashes, should develope more heating power in its combustion, than any anthracite also considered free from ashes. It is considered, therefore, that the trials as tabulated, really express the relation which the coal of Zerbe's Run bears to the dry anthracites, under the ordinary conditions of burning, and without regard to extreme economy.

TABLE I.

Showing the Comparative Efficiency of a good WHITE ASH SEMI-ANTHRACITE, and a good DENSE ANTHRACITE.

NAMES OF THE COALS. ZERBE'S RUN.	LBS. Coal burned.	LBS. Water evaporated.	Time in hours.	LBS. Clinker and fine Coal.	LBS. Ash and fine Coal	LBS. Total waste	Per centage of waste.	LBS. Water evap'd f'm 32°	LBS. Water evapor'd fr'm 212°	LBS Water evaporated per hour.	LBS. Water eva. to sq. ft of grate per hour.	LBS. C'l bur'd per hour to sq. ft. of grate.	
	26408	237427	72	1950	1718	3668	13.8	8.98	10.60	3299.6	108.12	10.20	Of the Zerbe's Run Coal, 1080 lbs. burned in a Stove with a fine grate, gave of earthy matter 66 lbs., making 6.11 per cent.
	8433	63525.6	25.30	290	529	819	9.7	7.53	8.89	2491.6	81.61	9.18	
	4149	31762.8	13.15					7.65	9.03	2415.5	80.99	8.97	
	8519	74113.2	26.35	297				8.70	10.26	2820	91.62	8.93	
	8200	63525.6	25	297				7.74	9.13	2541	82.26	9.01	
AVERAGES.....							11.7	8.12	9.58	2713.1	88.92	9.26	
HARD ANTHRACITE.													
	34118.3	261513.7	94.15	4380	2107.3	6487.3	19	7.66	9.04	2777.6	90.40	10.00	Of the Hard Anthracite, 2400 lbs. burned in the same Stove, made 430 lbs. of ashes and clinker, containing fine unburned coal. This is nearly 18 per cent. and shows the waste incident to the less ignitable coals when burned with a gentle draught.
	8208	63525.6	25.33					7.71	9.09	2507.9	80.26	8.94	
	8178	70658.6	25					8.64	10.19	2826.3	92.52	9.08	
	8110	63525.6	25					7.83	9.23	2541	83.16	9.01	
	8250	63525.6	25					7.70	9.07	2541	83.08	9.16	
AVERAGES.....							19	7.91	9.32	2638.7	85.88	9.23	
RHODE ISLAND.....	10280	63525.6	30.15	1008	very little.	1100	10.9	6.27	7.40	2102	69.85	9.44	

An inspection of this table shows, that the quantity of water evaporated, per square foot of boiler surface each hour, is far greater than is consistent with economy in the production of steam. It is, however, very common throughout New England, in large, as well as small, manufacturing establishments, to find exactly these conditions, and we deemed it the most sure test of the qualities of the coal, to place it under the same circumstances, as influence the great consumption. It is a point of great consequence in this connection, that our conclusions, — based on observations made under other influences, — that grates and furnaces, adapted to the dry and harder anthracites, are not well adapted to carry the economical results on this coal, nearly to their true places. Our observations, indeed, lead us to expect from a fuel, so easily ignited and burning its carbon so closely, a far greater production of heat, in an apparatus purposely constructed for developing the full amount. Compared with other anthracites, eight to ten per cent. of advantage, should be apparent from the mere difference in the weight of ashes, without reference to the impediment in a higher ratio, produced by an increased quantity.

The anthracite used in the comparison with the coal from Zerbe's Run, was from a bed on the Mount Laffy estate on the Mine Hill, north of Pottsville, and is considered one of the best kinds which reaches the eastern markets.

There is reason for the belief that this Zerbe's Run coal will find a special application as fuel for locomotive and steamboat furnaces; a point calling for experiments on a large scale continued some weeks under favorable circumstances. Another obvious application is, its use in mixture with other kinds of fuel, rendering the harder anthracites more combustible, or when mixed with bituminous coals, reducing the proportion of inflammable matter so far, as to allow of the combustion of the whole combustible matter of both coals. The advantages arising from mixing fuels, are often great in special cases, and the subject is becoming

one of importance generally. Practice has fully confirmed the theoretical conclusion, that it is often better to adapt the fuel to a particular construction of furnace, than to reconstruct a furnace, with reference to the use of a particular kind of fuel.

Respectfully,

A. A. HAYES,
Assayer to State of Mass.
1 Pine Street, Boston, 28th April, 1851.

REPORT

ON THE

CONBUSTIBLE QUALITIES OF THE SEMI-ANTHRACITES

OF THE

ZERBE'S RUN COAL FIELDS,

IN THE

SHAMOKIN BASIN, OF PENNSYLVANIA.

BY

PROF. HENRY D. ROGERS.

REPORT.

TO BERTRAM H. HOWELL, ESQ.,

President of the Zerbe's Run and Shamokin Improvement Company.

DEAR SIR:

IN obedience to your instructions, conveyed to me in January last, to investigate the combustible qualities, and relative commercial value generally, of the coals of the western end of the Shamokin Basin, in the vicinity of Zerbe's Gap, and to procure, if expedient, the coöperation of a competent scientific experimenter to aid me in the researches desired, I invited Dr. Augustus A. Hayes, of the Chemical works, Roxbury, a very able and distinguished practical chemist, to execute such experiments as we might conjointly propose, and to assist me with his suggestions. He embarked in the examination with much alacrity, and has, through his skill and long familiarity with questions connected with fuel and combustion, contributed a series of valuable and very interesting results. Upon these I have requested him to present a separate report. I shall myself use the leading facts procured, in connection with the determinations of various other experimenters upon fuels, for the purpose of enforcing certain general conclusions respecting the economic relations of the several kinds of coal; conclusions suggested in part by those authorities, in part by our own observations, and which seem to us to possess a bearing not only on your own

commercial interests, but on some of the most important enterprises of the times. Fuel, especially in its most compact and effective form of coal, is now so indispensable an agent in the arts, and is rapidly becoming so controlling an element in all the great mechanical operations of the world, that whatever tends to promote a closer acquaintance with the properties and special adaptations of its different varieties, cannot but be beneficial to the interests of society.

To convey a correct conception of the qualities of the coals upon which we have been experimenting, and the relations which those of the western end of the Shamokin Basin bear to the other varieties of anthracite, and to other coals generally, it is expedient that I should here offer a general preliminary description of the several gradations in composition and structure which coal exhibits, and also certain comprehensive facts, respecting the curious geographical distribution of the different kinds, as we trace them westward, across Pennsylvania, or other districts of the Appallachian mountains. We shall thus, by learning more precisely in what chemical and mechanical characteristics the particular variety of coal recently investigated differs from other known species, be better prepared to understand the causes of any economical excellence it may possess, and the special uses to which it is best adapted.

All the varieties of coal agree in containing, though in very different relative proportions, the following constituents.

Carbon, invariably the most abundant ingredient, and the gases hydrogen, oxygen, and nitrogen, the relative proportions of which are very influential in imparting to certain coals their special qualities. To these, — the organic products of vegetation, — we must add, a variable amount of earthy matter, — the ashes of the coal, when it is burned, — consisting generally of silica, alumina, oxide of iron, and sometimes a little lime, magnesia, potash, &c., and likewise frequently a small amount of sulphur.

It has been pretty clearly ascertained, by careful chem-

ical researches, that all coal, even the hardest and dryest anthracite, contains more or less of these various substances, and that in the different kinds they not only differ in their relative proportions, but in their conditions of chemical union with each other.

In the so-called bituminous varieties of coal, the three constituent gases are in chief part at least chemically united into the form of one or more oily, inflammable liquids, called bitumens, recognizable by the microscope in the cells of the coal; and it is equally clear from certain phenomena, such as the constant evolution of the gases in the free state from the pores of the coal, that another portion of these is locked within the coal in an uncombined but greatly compressed, and possibly liquid condition.

Thus it may be stated as a general analysis of all the bituminous coals, that they contain, besides their earthy ingredients; 1. Solid carbon; 2. Carbon, hydrogen, oxygen, and nitrogen, chemically combined in the state of bitumen; 3. A residual portion of the hydrogen, oxygen, and nitrogen in the form of free gases, easily volatilized; and 4. A small proportion, seldom more than one or two per cent. of free water mechanically present in its pores and fissures.

Now the essential difference between the bituminous coals and the anthracites is, not that the latter contain no gases or volatile matter, — for they sometimes possess as much as 9 or 10 per cent., — but that they are destitute of a perceptible amount of that chemical compound of the gases and the carbon, which is known as bitumen. In the dryest or most thoroughly de-bituminized anthracites, the hydrogen element amounts to about 2 or 3 per cent., and the oxygen and nitrogen together to about as much; and many facts make it highly probable that while a part of the hydrogen and oxygen are in combination in the form of water, and that some of the hydrogen and nitrogen is in the condition of ammonia, a residual portion

of all these three elements is in an insulated state, condensed in the pores of the solid parts of the coal.

In such anthracites, the carbon varies according to the purity of the coal, from 84 to 93 per cent., while the earthy matter usually ranges from 2 to 12 per cent.

The composition of a coal may be viewed in either of two aspects, and determined by either of two corresponding methods of analysis. In the one we may regard only the proportions of the several ultimate elements, the carbon, hydrogen, oxygen, nitrogen, and earthy substances which enter into it; in the other we may consider it as a union of certain specific combinations of these, namely of solid carbon or coke, with bitumen, the gases hydrogen, oxygen, and nitrogen in a free and condensed state, and some of these in the state of water and ammonia, and besides the earthy matters. The mere combustion of a bituminous coal effects the successive disengagement of these last named proximate constituents. Thus, in the first stage of kindling, the greater part of the free gases and of the water are exhaled at a relatively low heat, next a portion of the bitumen is converted into vapor, with disengagement of a part of its solid carbon, while the temperature is not yet high enough for actual ignition; still later the rest of the bitumen, and a part of the solid carbon burn off in flame and smoke, and finally the residual coke is consumed, and leaves only the earthy matter, the ashes.

The distinctive properties of the different kinds of coal are determined mainly, though not altogether, by the relative proportions of solid carbon and bitumen, which they severally contain. Coals are therefore styled bituminous, semi-bituminous, or anthracitic, that is, purely carbonaceous, — as they possess respectively, a full supply, half a share, or no trace at all of bitumen. When they contain as much as 18 or 20 per cent. of volatile combustible matter, they are to be designated bituminous coals; when less than 18 per cent., and more than 11 or 12 per cent., they claim the name of semi-bituminous; and when a

less proportion than 11 or 12 per cent., they are ordinarily designated anthracites.

Of those having more than 18 per cent. of bitumen, there are two general varieties, the *open-burning* and the *caking* coals. Both of these burn with much flame and smoke, and both swell into a vesicular coke in burning; but the open-burning kind coheres loosely, and permits the air to pass freely between its lumps, while the caking variety agglutinates more closely into a mass, and partially arrests the draught. This property of naturally caking or not caking, does not appear to depend, as very many persons suppose, merely on a greater or less abundance of volatile matter, for both the non-caking *splint coal* of England, and the *cannel coal* of that and our own country, rather exceed the Liverpool, and other caking coals, in their amount of bituminous or more strictly of volatile matter. The splint coals average as much as 36 per cent., the cannel coal seldom less than than 35, and frequently as much as 45 per cent., while the caking coals rarely exceed 32 or 34 per cent. of total volatile ingredients.

The semi-bituminous coals also, soften and swell into compact coke, but do not agglutinate at all, or only slightly; they are therefore equally eligible with the non-caking bituminous varieties, for certain purposes of combustion, while, as we shall presently see, they are preferable to them, in heating power, in proportion to the greater weight of solid carbon they contain.

The anthracites neither soften and swell or vesiculate, while burning, nor do they emit any smoke, strictly so called. Those varieties, however, which contain from about 7 to 10 per cent. of volatile matter, evolve in the early stages of combustion a visible amount of yellow carbonaceous flame, the product of the easily ignitible carburetted hydrogen gas, which is most probably present in the free state, in the cells and crevices of the coal, and not derived by decomposition from any bituminous matters. These are the free burning easily kindled anthracites. They are,

for the most part, fissured by numerous fine clefts or joints, by virtue of which, and of the expansible gases these inclose, the lumps spontaneously subdivide on the fire, in a greater or less degree, into small cuboidal fragments. These coals constitute, I conceive, a distinct variety, being, when of equal purity in regard to earthy matters, intermediate in color, lustre and specific gravity, between the semi-bituminous kinds on the one side, and the dry, hard anthracites on the other; and as they derive from their peculiar mechanical structure, and special chemical composition, definite and valuable qualities for several of the leading uses to which fuel is applied, I deem it convenient and proper to give them a separate designation — I shall, therefore, always allude to these as the *semi-anthracites.*

The true anthracites, constituting the fourth chief class of coals, contain, when free from mechanically imbibed water, from 2 to 5 or 6 per cent. of volatile matter, consisting of minute quantities of the atmospheric gases, and hydrogen, carburetted hydrogen, and also 1 or 2 per cent. of water very tenaciously retained.

These anthracites, when pure and not dislocated from the excessive pressure which attended the uptilting of the strata, have their fine intersecting joints or clefts far asunder, and nearly perpendicular to the grain of the coal, and they break with a semi-conchoidal fracture. They are harder and denser than any of the other coals, and by their firmer cohesion, their resistance to subdivision on the fire, and their destitution of inflammable gaseous matter, are the most difficult of all coals to kindle, and require the highest temperature for the maintenance of their combustion. The very hardest kinds yield an almost semi-metallic sound when struck, and in their slightly bluish tint and their faintly plumbaginous lustre, they suggest plainly their affinity in composition to true graphite or black-lead. In all these and their other characteristics, the genuine anthracites give evidence of their having been exposed since their deposition to

a far greater intensity of terrestrial heat than any of the other kinds of coal. Anthracite is unquestionably the metamorphic form of ordinary bituminous coal, and has derived its peculiar composition of a nearly pure carbon, and its other important qualities, from the slow expulsion under great pressure, of the volatile parts of the coal, through the distilling action of a high temperature, pervading the strata enclosing it.

To a somewhat less elevated or prolonged heat in the earth's crust, we are equally well entitled by all geological testimony, to ascribe the more imperfect removal of the gaseous elements in the instance of the semi-anthracites; and to various yet feebler degrees of heating, we are manifestly compelled to assign all the corresponding grades of bituminization, met with in the semi-bituminous, and the dryer bituminous coals.

These general introductory views of the composition and structure of the several leading species of coals, will be seen to possess much practical importance in suggesting the proper uses and adaptations of the respective varieties, and the conditions under which each species should be burned, to insure the highest economy of their heating power. Each of the four dominant kinds of coal described, has been found by experiment to subserve, better than the rest, some appropriate end or ends, in the multifarious operations of the arts; but the practical man is continually deceived in his calculation of the economy of his fuel, through inattention to the chemical laws of combustion, and correct conceptions of the true nature of the special variety of fuel he is using. Without such knowledge, the whole economic problem of his coal and his furnaces is but guess-work, the moment he essays a new variety, or introduces any material alteration in his mode of burning even a familiar species.

Geographical Distribution of the several Species of Coals in their Gradation from Anthracites to full Bituminous Coals.

There prevails a very interesting law of gradation, in the quantity of volatile matter belonging to the coal, as we cross the Appallachian basins from the southeast towards the northwest.

The gradation may be thus briefly described. Crossing the Appallachian coal-fields, northwestward from the great valley, to the middle of the main or western trough, by any section between the northeastern termination of the formation in Pennsylvania, and the latitude of Tennessee, we find, as the result of multiplied chemical analyses, a progressive increase in the proportion of the volatile matter, passing from a nearly total deficiency of it, in the dryest anthracites, to an ample abundance in the richest caking coals.

The lists of analyses contained in the Reports of the Surveys of Pennsylvania and Virginia, and similar data not yet published, show the following as the general proportion of the bituminous matter, in the different belts of the formation, as we cross the region from southeast to northwest.

First. In the most southeasterly chain of basins, the coals are, for the most part, genuine anthracites, and semi-anthracites, containing sometimes a small percentage of bitumen, and always a little gaseous matter, chiefly hydrogen. The quantity of the volatile matter varies according to geological locality, from about six to twelve or fourteen per cent. This first belt of basins embraces all the anthracite coal-fields of Pennsylvania, the slightly bituminous ones of Broad Top on the Juniata, of Sleepy creek, of the Little North mountain, of Catawba creek, Tom's creek, Strouble's run, and Brushy ridge, in Virginia. The coal of the Little North mountain, is, however, a true anthracite. All of these coal-fields, and insulated patches of the formation, belong to the most disturbed portions of the Appallachian

chain, and they are associated with some of the boldest flexures and greatest dislocations of the whole region. The first or southeastern anthracite basin of Pennsylvania, presents innumerable sharp flexures and close plications, even with inversion, of the strata.

Secondly. In the next well-defined range of basins further towards the northwest, that namely of the Allegheny mountain, and the general escarpment of which it is a part, the proportion of volatile matter varies usually from sixteen to twenty-two per cent.; but is generally about eighteen or twenty per cent. This belt includes all the coal-fields, situated immediately to the northwest of the Allegheny mountain, in Pennsylvania; also, the Potomac basin, in nearly the same line, and the coal-fields of the Little Sewell, and the eastern side of the Big Sewell mountain, in Virginia. The position of this belt of the coal-measures is somewhat west of the region of steep flexures of the strata, and beyond all the considerable dislocations; while it embraces a very few extensive, regular, and nearly symmetrical anticlinal axes of the flatter form, distinctive of their intermediate position between the east and west.

Thirdly. The great Appallachian basin, with its subordinate troughs, forming the wide coal-field watered by the Ohio river and its tributaries, embraces a series of coal-beds, which are all distinguished by a still larger amount of volatile matter. In crossing the breadth of this large coal-field, we find a very material alteration in the character and composition of the coal. Along its eastern side, or near the last considerable axis of the Appallachian chain, the amount of volatile matter is commonly from twenty-five to thirty-five per cent. Westward of this line, on the Monongahela river, both in Pennsylvania and Virginia, the proportion approaches to forty per cent., while still further in the same direction, or near the Ohio river, it ranges from forty to even fifty per cent., according to local circumstances. In this most western or main coal-field, the flexures of the strata are extremely gentle, and comparatively wide apart;

but, even here, we observe a beautiful progression in the amount of the bitumen, as we recede from the very low axes which occupy the southeastern side of the great plain. What renders the foregoing comparison of the several ranges of the coal-formation particularly exact and satisfactory is, the circumstance, that, in more than one instance, we are enabled to trace the very same coal-seam through its various degrees of bituminization, from an almost true anthracite, to a form in which it possesses a full proportion of volatile matter. Thus the great Pittsburg bed, to take this as an example, contains on the Potomac, in some localities, as little as 15.5 per cent., but near the eastern margin of the great western basin, as at Blairsville, and again in Virginia, it has about thirty-one per cent., and towards the middle of the main basin at Pittsburg and on the Kenawha, as much as from forty to forty-three per cent.

The cause of the different degrees of de-bituminization of the coals, in different parts of their range, I am disposed to attribute to the prodigious quantity of intensely heated steam and gaseous matter, emitted through the crust of the earth, by the almost infinite number of cracks and crevices, which must have been produced during the undulation and permanent bending of the strata. All the phenomena of modern earthquakes and volcanos, warrant us in supposing that the elevation of our coal rocks, if effected in the manner I have imagined, must have been accompanied by the escape of an immense amount of hot vapors, the chemical and thermal agency of which cannot be overlooked, upon any hypothesis of the rending and uplifting of great mountain tracts. It is easy to conceive, that the coal, throughout all the eastern basins, if thus effectually steamed, and raised in temperature in every part of its mass, would discharge a greater or less proportion of its bitumen and other volatile constituents, as the strata were more or less frequently and violently undulated by earthquake action. It is also obvious, that the more western beds, remoter from the region of active movements, less

crushed and fissured, and presenting a greater resistance to permeation by the subterranean vapors, would, in virtue of their mere geographical position in the chain, be much less extensively de-bituminized. The striking fact that we nowhere, not even in the most dislocated and disturbed districts of the anthracite coal-field, find any traces of true igneous rocks, that, by their contiguity to the coal could have caused the loss of its bitumen, is a circumstance in their geology, which goes far to confirm the truth of the hypothesis. Precisely in proportion as the flexures of the strata diminish in our progress westward, does the quantity of bitumen in the coal augment; but it is difficult to conceive how any such law of gradation could have been the result of a temperature transmitted by conduction from the general lava mass beneath the crust, for that would imply a corresponding increasing gradation in the thickness of the crust, advancing westward under the coal-fields; whereas such an inference is in direct conflict with the fact of the general diminution westward of the Appallachian rocks, besides being inconsistent with all correct geothermal considerations, which forbid our imagining so unequal a conduction to the surface, of the earth's interior temperature.

Corresponding with the progressive augmentation northwestward of bituminous matter in the coals of the whole Appallachian chain, is a gradual but perceptible increase of volatile constituents in the anthracites of Pennsylvania, within the more restricted limits which they occupy. In this part of the chain, however, the direction of the maximum rate of softening of the coal and introduction of volatile and bituminous matters would seem to be nearly due westward, or perhaps more exactly towards the west-north-west. The gradation will be found to be not absolutely regular, but to fluctuate within quite narrow extremes, as might be anticipated from the very obvious relation of the degree of de-bituminization, to the varying degrees of heat and disturbance which have locally affected the strata. Even in the same locality, the closely adjacent

beds will differ by two or three per cent. in their quantity of volatile matter.

Reviewing the whole anthracite coal-field, and comparing the coals in their average composition, we find that from the Lehigh and the Lackawanna streams westward, to Black Spring Gap in Dauphin, and to Shamokin, their usual proportion of total volatile matter is about 5 per cent. Of this generally $1\frac{1}{2}$ per cent. is moisture, and the other 3 or 4 per cent. hydrogen, oxygen, nitrogen, and other gases. The coal between these limits may be all classed under the one denomination of genuine or hard anthracite. But for a few miles from the meridian mentioned, extending in the southern Basin from Black Spring Gap to near Rausch Gap of Stony Creek, and in the Wiconisco Basin from Klinger's Gap westward, and in the Shamokin Basin from a little west of Shamokin Gap to the extreme western end of that Basin, the coals show a gradual but decided increase in their quantity of volatile matter, with a progressive departure from the characteristic hardness, lustre, and color of the true anthracites. These are the limits of what I have termed the *semi-anthracites*, which are nowhere so well characterized, so well developed, and so accessible, as in the Shamokin Basin for two or three miles both east and west of Zerbe's Gap, near Trevorton. Between the meridians now defined, the average amount of volatile matter in the coal is about 9 per cent., some 6 or 7 per cent. of which is combustible gaseous matter, and the rest is moisture and non-combustible gases. As already mentioned, these gaseous anthracites are traversed by more numerous fissures than the harder kinds further east, and as a consequence, their mode of burning is essentially different. A very regular gradation in the increasing frequency of the little joints alluded to, is perceptible in tracing these coals from where they merge into the compact anthracites on the one side, to where they pass into the semi-bituminous coals on the other. From a third to a half of an inch is the prevailing distance

which separates the cracks in the genuine semi-anthracites of Zerbe's Gap, of the west end of the Wiconisco Basin, and of the eastern part of the Dauphin Basin; and it is an interesting fact, that they are almost absolutely parallel with each other, and constitute but one set or system of joints, whereas the softer semi-bituminous coals are traversed perpendicularly to the lamination of the coal, by *two* or more sets of still more closely adjacent fissures, by which their laminæ are throughout extensive districts rendered minutely columnar. The economic considerations connected with the respective effects of these modes of fissuring, will be discussed in another section of this paper.

From about two miles east of Yellow Spring Gap of Stony Creek, westward along the Dauphin Basin to its termination within ten miles of the Susquehanna, the proportion of bitumen in the coal increases from an average of 10 per cent. to an average of 14 or 15 per cent., fluctuating in the different beds from 8 to 12 per cent. at the eastern end of this belt, and from 13 to 17 at the western; this range includes then the dryer class of semi-bituminous coals, and towards its eastern limit some true semi-anthracites. And the same seams which at Yellow Spring Gap are dry semi-bituminous coals, are all of them semi-anthracites at Rausch Gap, only $4\frac{1}{2}$ miles further east. Into the question of the sources of this difference, in the amount of volatile matter remaining in different closely contiguous coals of any group, either semi-bituminous or bituminous, I shall not here enter, as this is not a point of any obvious practical moment.

By the foregoing description of the progress of the gradation in bituminous matter, it appears, that in the Dauphin Basin, the transition to semi-anthracite commences somewhat earlier in this southern coal-field, and in the Shamokin Basin, than it does in the Wiconisco coal valley, where this variety is confined almost to the western end of the trough. It is also shown that the semi-bituminous coals

are found only in the Southern Basin, and that the transition from the semi-anthracites to these there takes place, considerable east of the westernmost meridian of the semi-anthracites of the two other Basins. Had the Zerbe's Run Coal Valley been prolonged but a very few miles further westward, the present rapid increase in that direction of the volatile matter in this coal, shows that it too would have included the semi-bituminous class.

The causes, not only of the general gradation in composition, but of the local differences in the progress of this curious transition in the bitumen above described, are plainly indicated in the particular geological structure of the respective coal-fields. It would be out of place in this Report to examine more minutely than has been already done, the whole theory of the cause of the de-bituminization of our coals; but it is important here to observe, that the phenomena are truly those of a baking and metamorphism of all the strata by an intense and pervading heat; that this heat has obviously been in greater excess in the eastern than in the western tracts of the anthracite country, and has been even differently operative, upon the different beds of coal, in proportion as these were incased in more or less conducting strata, or in strata more or less pervious to the escaping, volatilizing gases and bitumen. Independently of the satisfactory evidence presented by the transition of the coal itself, we have proofs, in the altered character of the other members of the formation, — the shales and sandstones, — and in the conditions of the rocks external to the coal basins, that the igneous action was most intense towards the east. In that quarter, the shales or mud rocks of the Kittatinny valley, have been so thoroughly baked, as to have been converted into roofing slate; and not only this formation, but all the other strata from the Schuylkill and the Lehigh to the Delaware rivers, are traversed by a system of close-set, parallel, uniformly dipping cleavage planes, in token not to be overlooked, that the drying and polarizing agency of internal heat was here exerted in its fullest

energy. Westward from the sources of the Schuylkill, both within and outside of the coal-fields, the parallel southeast dipping cleavage pervades the argillaceous masses in a constantly declining degrees, so that the same rocks, which near the Lehigh are almost indefinitely divisible into thin parallel slates, have had in the country between the Schuylkill and the Susquehanna, this polarity less intensely imparted to them, and break by two or three intersecting sets of planes, either into rhombs or elongated horizontal pencils. This declension in the metamorphism of the shales or mud-rocks, is in parallelism with the similar change in the cleavage of the coal itself, which in the anthracites and semi-anthracites occurs only in one direction, and is parallel, and in the softer semi-bituminous variety in two or more intersective directions, resulting in a columnar fracture.

But we have still more positive proof of the truth of the view here taken, that the eastern portions of these anthracite fields were more invaded than the western by volcanic heat, in the fact, that it is only adjacent to the former, that any igneous mineral dykes or veins of molten matter injected during the elevation of the coal strata, burst through the crust to the surface. Along the chain of the South Mountains or Highlands, from the Delaware to the Schuylkill, occur numerous intrusive dykes of magnetic iron ore, greenstone, and other igneous rocks — while in the humbler range of hills scattered between the Schuylkill and the Susquehanna, these injections are much more rare. In the eastern quarter, therefore, the earth was far more violently rent than in the western, and we are conducted to the almost necessary inference, that the districts respectively opposite these differently disturbed and heated belts, were themselves in a somewhat corresponding degree differently heated; for although not a single intrusive vein or dyke is to be met with in all the anthracite country, there evidently issued through the coal strata, a copious efflux of hot volcanic gases and steam by the differently heating

and distilling power of which in the different districts, the coal itself was variously de-bituminized and metamorphosed.

The chief Conditions in the Composition and Structure of Coals, which influence their practical Value.

It will assist us to estimate more correctly, the relative practical values of the coals examined, if, before describing their composition and actual performance, we consider the various qualities which good coals should possess, and the extent to which certain conditions in their constitution influence their efficiency as fuels.

The chief useful applications of coal, at the present day, are: to the warming of houses, the generating of steam, the smelting of iron and some other substances, the burning of bricks and lime, and the manufacture of illuminating gas.

For all these and sundry other uses, excepting the making of gas, the semi-anthracites, it is conceived, will be found quite as well suited as the hard, dry anthracites, while they are undoubtedly even better adapted to some particular applications.

A good anthracite for domestic purposes, should be as free as possible from *sulphur* and from *ashes*, and it should ignite readily, and maintain its own combustion until entirely consumed, and not under too intense a temperature. A most essential requisite to the health and comfort of all communities, living in cool and especially in variable climates, is the maintenance of a tolerably uniform in-door temperature; but it must be acknowledged that the harder anthracites, burned in the crude and unscientific modes almost universally in use, absolutely resist control in this respect. When fully kindled, in quantity enough to make a lasting fire, either in an open grate or a stove, almost any compact anthracite will heat the space around it to excess, and moreover cause a dryness in the air, which is extremely unwholesome. These coals can only burn at a very ele-

vated temperature and with an abundant admission of atmospheric air, and they therefore oppose much difficulty to all attempts, unless made with very exact adjustments, at restraining their combustion to the satisfactory point of a low, mild heat.

The semi-anthracites, such as those of Zerbe's Run, are susceptible in this respect of much more easy management. Under a strong draught, which they require for full activity of combustion, these coals (as our Table of comparative results will show) burn quite as fast and create as extreme a heat, as do the hardest anthracites; but with the ordinary supplies of air, they consume slowly, and give off only a moderate and comfortable temperature.

The chief reason of this difference is, in their readily breaking into small fragments on the fire, and damping thereby the draught by the increased friction which the air encounters. When the current of air, on the contrary, is strong, the effect of the greatly extended surface resulting from this subdivision, overrules the influence of the friction, and these coals then burn with a rapidity and an intensity of heat, which give to them an efficiency for other purposes, decidedly superior to that of any but the very purest and quickest burning among the true anthracites. The greater amenability to control of the softer coal, compared with that of hard refractory anthracites, renders it especially well suited for domestic consumption in stoves and cellar furnaces, as already amply demonstrated by numerous and protracted trials. In these arrangements it is altogether more easy than with common hard coal, to maintain a steady and sufficient temperature in an apartment or throughout a house for many hours together, or even a whole day and night, without a renewal of the fuel. Its important property of burning at a relatively lower temperature, keeps it enkindled to the last, and as a consequence, it leaves behind it after combustion, almost no unburned residuum. Not so, with the densest dry anthracites. These rage for a while under a moderate strength of draught, and then at a point

much short of entire consumption, they die out from decline of temperature, leaving a serious amount of fuel wasted, and causing in household economy no trivial inconvenience. To obviate this form of waste and extra labor, the fires are replenished with fresh fuel when it is not required, and then an almost insupportable heat is created, and a still larger waste with much increased discomfort, are the consequences.

Another material point of difference in the fitness of the two classes of anthracites for domestic use when burned in open fires, is in their sensibly dissimilar influence on the dryness of the surrounding air. The atmospheric moisture exists as an independent gas, inter-diffused with the other less variable elements of the air. Any local source of aqueous evaporation, or of chemical production of water, as in the combustion of wood or of bituminous coal, suffices to spread a more or less diffused humidity throughout the rest of the space, by virtue merely of the power inherent in every vapor and gas to diffuse itself among the others, uninfluenced by mechanical currents. Thus an actively blazing wood fire, by producing a copious supply of watery vapor in its smoke, serves slightly to moisten the atmosphere around, because, notwithstanding that the flow of air is towards the fire-place, the humid particles percolate through the current by a more active force in the opposite direction. But such is not the case where a fuel, like a hard dry anthracite, is burning in presence of the atmosphere of the room. Being almost destitute of hydrogen, it developes by its combustion little or no water, while at the same time it creates a great avidity for moisture in its own smoke and in the air around it, by the high temperature to which it heats these. It therefore occasions a filtration or diffused movement of the watery particles of the atmosphere of the room, towards the fire-place and not from it. A mass of such fuel ignited is, in other words, an *absorbing vacuum* for moisture, while a blazing wood or bituminous fire is a dispersing *plenum*. In this opposite action

of the two kinds of fuel, we find the explanation of the obvious and acknowledged difference, in the agreeableness and wholesomeness of their respective open fires.

Now it is deserving of remark, that this detrimental, drying action of the anthracites is possessed in a decidedly smaller share by the soft, free-burning, and gaseous semi-anthracites, several of the characteristics of which depend on their containing a sensible proportion, often one half as much as belongs to bituminous coals, of the important moisture-producing element, hydrogen. All the non-bituminous coals desiccate the air too much; but these do this least, and will be found, upon this account, decidedly the most wholesome class, if open fires are used.

Another very important application of fuel, is the development of steam, either for warming buildings or propelling machinery. In this latter function, as the foremost of all the agents employed by civilized man for his industrial ends, and as incomparably the most condensed form of mechanical power which he can hope to wield, coal is rapidly becoming the chief material minister to human progress. Whatever, therefore, relates to a correct theory and practice in applying it to steam, must be regarded as of paramount interest. The present experimental inquiry into the properties and relative value of the semi-anthracites, — a variety hitherto but little investigated, — is therefore, upon general considerations, no less than local ones, deserving of attention.

The principal requisites of a good fuel for steam purposes are easily enumerated.

1. It should possess a high absolute evaporative power.

2. It should at the same time, as far as is compatible with the foregoing property, kindle readily, and burn with great celerity, generating a large body of steam in a short time.

3. It should be easily managed and steady in its combustion, and to this end its ashes or earthy matter should tend, as little as possible, to choke the draught of the

grate by fusing, even at an extreme heat, into an adhesive clinker.

4. The fuel should be free from any excess of incombustible matter, as this, all other things being the same, will materially impair its efficiency; and its ashes should produce but little clinker.

5. It should be exempt from any considerable amount of sulphur, for this tends to corrode the flues, and is otherwise detrimental.

6. Whatever volatile matters it possesses should not be bituminous, but should be in the condition of the free gases, susceptible of ignition or disengagement without smoke; and these volatile matters should not exist in any greater amount than will suffice to give rapidity of combustion to the fuel; any larger proportion is at the expense of its heating power.

7. A fuel should not be too cohesive and refractory on the fire, nor yet too tender and divisible. In the one case its combustion will be slow and irregular, and in the other it will be still slower for want of the requisite draught. A certain degree of spontaneous frangibility, such as is shared by some of the less resisting anthracites, and by many of the firmer semi-anthracites, appears from practice and experiment to be the structure best suited to extreme vigor and steadiness of combustion.

8. For certain purposes of domestic consumption, coals should be capable of sustaining a mild and steady combustion, and of remaining ignited at a low temperature, with a comparatively feeble draught.

9. For certain uses, it is important that a coal should unite with a high evaporative power, such a degree of density and structure combined, as will enable it to contain a relatively large amount of carbon in a given space. This capability of being economically stowed or packed away, is a point of daily increasing consideration. The difference between the least and the most stowable anthracites, is as much as sixteen per cent., and between the closer packing

anthracites and the lighter and more open bituminous coals, it even exceeds twenty per cent.

10. It is likewise desirable that a coal should possess sufficient tenacity in the lump, to bear the abrasion incident to its transportation, without serious waste by reduction to fine coal.

These are the principal qualities in coals which materially influence their economical value. No one variety will ever be found to unite them all, for some of them can hardly co-exist in a high degree in the same specimen. The relative worth to be assigned to these several desiderata, is itself variable, with the uses to which the fuel is to be applied. But having a specific application in view, it is easy to ascertain what union of compatible qualities will insure to a coal the highest possible efficiency. This once determined on, the records of judiciously conducted practical experiments, will then prove the proper guide in selecting the kinds required.

If I now present a condensed synoptic view of the composition and comparative efficiency of a number of well known and characteristic American and British coals, derived from the able experiments of De la Beche and Playfair, and the full and careful researches of Johnson, and from our own recent trials, the reader will have before him all the data necessary and accessible for determining the general relative excellence of the several species, and the rank which each particular coal can claim, when measured by either of the practical standards established.

In offering this Tabular Statement, it is expedient to remark, that in all such comparative estimates of the values of different fuels, strict impartiality and accuracy require that the conditions under which the different varieties are tested, should be modified, as far as possible, to meet their individual peculiarities. A just comparative view will embrace not merely a faithful account of the chemical and physical characters of the several coals, but the results of sundry trials of their efficiency in numerous modes of their

application, as in warming, generating steam, and smelting, and with the circumstances variously adapted to bring out the fullest economy and power of each kind of fuel. Our investigation of the semi-anthracites of Zerbe's Run, embraced, together with a chemical analysis of several average specimens, a determination of their usual specific gravity and power of being economically stowed, and in addition, many comparative trials of the combustible efficiency of the coal in open fires and stoves, and under a set of four well arranged steam-boilers. No actual experience has yet been had touching the suitableness of the semi-anthracites to the various processes of iron making, but several important inferences may be deduced from what has been ascertained of their composition and structure, and their fitness for other uses, involving the same combination of qualities essential to a good smelting coal.

In the experiments made upon the evaporating power of the coals, due care was observed to insure comparable results, so far as was practicable, upon good boilers, without any special adjustments for adaptation to differences in the fuels and working for a copious production of steam. As the furnaces and flues connected with these boilers were planned especially to meet the requirements of the harder kinds of anthracite, — the grate bars being three-fourths of an inch apart, — the conditions have been rather adverse than otherwise to the impartial claims of the coal from Zerbe's Run; but I have chosen that any disadvantages in the trials should be on that side rather than on the other.

It will be seen that in planning and conducting these researches, we have not aimed at any extreme scientific precision, or even at procuring results by perfection in the apparatus or otherwise, beyond such as are easily obtainable in the way of good daily working practice. The two kinds of coal were deemed sufficiently alike, after all, to yield approximately comparable values, and it is very doubtful whether the most refined apparatus, unless vari-

ously adapted to the peculiarities of each fuel, where the coals are more diversely organized, as in comparative trials between the bituminous and anthracitic varieties, can ever exhibit more closely than ours has here done, the respective merits of the different species.

While, therefore, we do not pretend to rank our experiments with the above-mentioned recent skilfully conducted observations of De la Beche and Playfair and their assistants, or the elaborate researches of Prof. Johnson, and while we are aware that the very active blast we used was incompatible with as economical a combustion as those experimenters produced; we are content, for the sake of affording an insight into the relative efficiency of the semi-anthracites, to tabulate our results with those of the esteemed authorities we have named.

The design of the General Table which here follows, is to present in one condensed comparative view the more practically important physical and chemical characters, manner and rate of burning, and evaporative power and activity, of the chief American and foreign coals hitherto subjected to experiment, and to show moreover, by a series of impartial averages, the relations to each other, in these respects, of the four great classes into which the coals naturally rank themselves.

TABLE II.

	Names of Coals.	DENSITY. Specific gravity.	DENSITY. Weight of 1 cubic foot broken in lbs.	DENSITY. Stowage of 1 ton in cubic feet.	COMPOSITION. Volume comb. matter in 100 parts	COMPOSITION. Fixed carbon in 100 pts.	COMPOSITION. Earthy matter in 100 pts.		CONDITIONS OF THE COMBUSTION. Weight of coals bu.ned.	Clinker alone fm. 100 lbs. Coal.	Total Waste in Clinker & Ashes	Pounds burned on sq. ft. of grate pr. hour.	Hours required to get up full action.	EVAPORATION. Pounds of water evaporated.	Pounds water evaporated fm. 212° to 1 lb. coal.	Rate of vaporation, or lbs. evpd. pr. hr. to sq. ft. gt.	RANK. In the order of combined evaporative speed and power for equal bulks.	AUTHORITIES
Hard Anthracites.	Rhode Island . .	1.79			3.00	77.	16.00		10560.	10.00	10.90	9.44		63525.6	7.40	69.85		Hayes.
	Beaver Meadow, (mean of 3 kinds.)	1.55	55.06	40.03	2.52	90.20	6.13		4097.5	1.00	9.35	6.48	3.15		9.54	61.82	3403.80	Johnson.
	Lehigh	1.59	55.32	40.50	5.28	89.15	5.56		3838.2	1.08	7.22	6.95	3.27		8.93	61.16	3383.31	"
	Forest Improvem't.	1.47	53.66	41.75	3.07	90.70	4.41		3810.	0.81	6.97	6.52	3.32		10.06	65.69	3519.55	"
	Lackawanna. . .	1.42	48.89	45.82	3.91	87.74	6.35		4112.5	1.24	8.93	6.45	2.67		9.79	63.15	3087.40	"
	Mount Laffy . .	1.54	53.50	41.87					8100. largest export 34118	12.80	19.00	9.23 highest 10 00		63525. largest expt 281513.	9.32 highest, 10.19	85.88 hgst. 92.32 9.09×10.19	4594.6 highest, 4949.8	Hayes & Rogers.
	Welsh Anthracite.	1.37	58.25	37.23	5.50	91.44	1.52				9.58	8.65			9.46	81.83		De la Beche & Playfair.
	Averages of the 4 first Penn. Anthracites, with Johnson's Apparatus. .	1.50	53.23	42.02	3.69	89.45	5.61	.044	3964.5	1.03	8.12	6.60	3.10		9.58	62.93	3349.8	
Semi-Anthracites.	Zerbe's Run, (mean of 5 trials)	1.40	53.73	43.07	7.31	84.25	6.11	.000	8000. largest export 26408.	3.45	11.70	9.26 highest 10.20		64960. largest expt 237427.	9.58 highest, 10.60	88.92 highest, 108.10	4777.4 highest, 5848.2	Hayes & Rogers.
	Lyken's Valley. .	1.39	48.56	46.13	6.88	83.84	9.25	.091	2471.	4.40	12.24	6.92	2.63		9.46	65.46	3973.66	Johnson.

Semi-Bituminous Coals.	Dauphin, Yellow Spring				11.00	78.00	10.10										Rogers.
	Dauphin, Ratling Run Gap . . .	1.44	50.54	44.32	13.57	74.24	11.49	.269		3.50	16.36	6.86	0.83		9.34 highest, 9.66	64.07	3238.09	Johnson.
	Cumberland, Md., (mean of 6 samples)	1.35	53.13	42.17	14.20	73.95	10.41	.714		3.12	10.70	7.10	1.45		9.98	70 85	3764.26	"
	Welsh Semi-Bituminous, (average of 5 varieties) * .	1.33	58.60		13.4	81.88	4.72	.610							8.94	84.5		De la Beche & Playfair.
	Averages of the above Penn. and Md. S. B. Coals. .	1.39	51.83	43.24	12.92	74.73	11.33	.531		3.31	13.53	6.98	1.14		9.66	67.46	3496.4	Johnson.
Bituminous Coals.	Richmond Va. Cls., of the Oolitic Epock; (mean of 11 Collieries) . . .	1.34	49.25	45.71	29.43	58.10	10.90	1.232	3606.4	4.89	11.78	7.41	1.33		8.07	59 80	2945.15	Johnson.
	Foreign Coals, (mean of 6 kinds †)	1.34	50.00	44.86	31.81	57.66	8.44	0.433	3247.7	4.20	8.71	8.89	0.93		8.05	71.56	3578.00	Johnson.
	West of Allegheny Mts., (mean of 2 kinds. ‡)	1.26	47.23	47.43	30.28	56 68	6.02	0.160	2465. Cannelton.	1.28	6.68	11.09 Cannelton	0.50 Cannelton		7.77 Cannelton 7.34	81.40 Cannelton	3844.50	Johnson.
	Averages of the above Bituminous Coals	1.31	48.82	46.00	30.50	57.38	8.45	0.608	3106.3	3.45	9.05	9.13	0.92		7.96	70.92	3456.0	
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	

* The Coals are, Graigola, Ward's Fiery Vein, Binea, Pentrefelin, and Duffryn. † Pictou, Sidney, Cunard's Pictou, Liverpool, Newcastle, Scotch. ‡ Pittsburg, Cannelton.

We have it in contemplation to undertake, should opportunity permit, some additional trials upon the relative evaporative power of the semi-anthracites of Zerbe's Run, under a slightly modified arrangement of the flues connected with the boilers, adapting them better to meet the requirements of each kind of coal to be burned. We shall then be able to test fairer samples of the Zerbe's Coal; for that which we have hitherto used was mined from a very shallow depth beneath the soil, and was therefore too much saturated with water and too friable to represent impartially the average qualities of the bed.

Let us now review concisely, by aid of the above table, first, the relative values of each leading class of coals, and secondly, by a close examination, that of the Zerbe's Run coal, in comparison with the rest. In this inquiry it will be proper to judge of the rank of each kind of coal by the extent to which it possesses the several qualities already mentioned as the chief requisites of every good fuel. But it must be carefully borne in mind, that, though the numerical results here exhibited offer a fair approximate measure of such relative rank, they are not to be adopted in certain cases without allowance for the modifying influence of differences in the modes of measuring and burning the coals.

The *first* of the qualities to be compared is that of divisibility during combustion. This property, due chiefly to the degree in which the respective coals are intersected by joints, but due also in part to a condition of the cohesive force, and to a low power of conducting heat, as in unannealed glass, is possessed in the least share by the more compact of the anthracites, and reaches its maximum in the softer semi-anthracites. In the semi-bituminous coals of some districts, that of the Allegheny Mountain, for example, the mere mechanical subdivision by innumerable intersecting cracks is in its highest excess, and leads to much waste under severe handling and rough transportation, but upon the fire the minute cubical and columnar fragments cohere together as they coke, and the benefits of that degree of

dissolution seen in the free-burning semi-anthracites are to a great degree lost.

It has been already stated that the semi-anthracites of the western end of the Shamokin Basin show the advantages in a sensible degree of this fissured structure. While the actual heating power of the coal, when aided by a proper draught, is not at all impaired by it, the raté of the combustion and evaporation is materially hastened. The strong cohesion of the true anthracites, and the agglutination of the fragmentary semi-bituminous coals, cause these in different ways to retain more of the lump form upon the fire, but the Zerbe's Run semi-anthracite opens to the current of oxygen a prodigious increase of surface for combustion. When we reflect that a lump of fuel burns only at its surface, that the activity of the combustion is in proportion, — other things the same, — to the amount of oxygen which can reach an equivalent amount of fuel surface, in a given time, and that this amount augments progressively by the subdivision of the fuel until it is checked again at a certain point by the retardation of the draught from the increased friction; we shall comprehend at once why a particular degree of divisibility, such as we find in the Zerbe's Run coal, may be the most favorable of all for producing high rapidity of combustion. The burning of carbon in atmospheric air, is in part analogous to the dissolving of any other solid in any other fluid. Chemically regarded, it is a case of solution with formation of new compounds. But such solution is notoriously promoted and hastened by subdivision of the solid body, as we witness in the every-day practice of reducing sugar, salt, and especially the substances which most resist dissolving, to small fragments, or even to fine powder.

The *second* element of practical value in the coals, the first introduced into the Table is, their capacity for *economical stowage*, deduced, not from the specific gravity of solid pieces, but from the ascertained weight of a cubic foot measure of the coal in broken fragments of a standard size. The degree

of compactness into which a coal in a state of lumps will stow itself, by no means depends altogether on its specific gravity. It is largely influenced by the shapes into which the coal naturally breaks; those varieties, as it has been well remarked, packing with least waste or intersticial space, which split by parallel joints and form cubes and other rectangular figures with flat surfaces. And again, the total quantity of efficient fuel which can be stowed in the lump form in a given bulk, will be in proportion, not simply to its weight in fragments, per cubic foot, but to this element and that of its purity from earthy or incombustible matters combined. The present condition and future prospects of ocean steam navigation, where the fuel room necessarily encroaches so largely on the freight room of the steamers, make this quality of stowing closely, an element of great importance. Indeed, the time seems fast approaching, when no other coals will be chosen for the great and growing purpose of replacing the use of the wind upon the seas, but such only as unite in the highest compatible degree, the three primary qualities of *dense stowage of efficient combustible matter, high evaporative power, and great activity of combustion.*

It will be seen upon consulting Table II., that though the average specific gravity of the hard anthracites of Pennsylvania exceeds that of the Zerbe's Run semi-anthricite in the ratio of 1.50 to 1.40, their weight per cubic foot in the broken state is very nearly the same, their capacity for stowage being in the near proportion of 43 to 42.

Compared with the semi-bituminous coals, this semi-anthracite shows an almost exactly equal power of packing, bearing in this respect to the average of the Dauphin and the Cumberland coals the ratio of 43.07 to 43.24 cubic feet per ton. Here, however, it requires to be noticed, that difference of specific gravity enters as a fallacious element, increasing from the fact of the superior weight of slate over true coal, the apparent quantity of real fuel in the cubic foot of the semi-bituminous coal beyond its actual amount.

These semi-bituminous coals exhibit an average of 11.33 per cent. of earthy matter to 6.11 per cent. in the semi-anthracite, showing a decided disparity in the proportion of effective combustible matter which the ton weight of each will stow. Where the two classes are of equal purity, the semi-anthracites will, in the larger majority of specimens, be found to be the heaviest, and to occupy, therefore, either solid or when broken, the least bulk.

Comparing again the nearly equal powers of stowage of the three already-mentioned classes of coals with that of the bituminous coals, both domestic and foreign, we find a materially greater difference; these latter requiring on an average as many as 46 cubic feet to hold one ton of the fuel. Between the densest Beaver Meadow anthracites, measuring 40 cubic feet to the ton, and the least compact Cannelton bituminous coal, taking rather more than 47.5 cubic feet, the excess of bulk is nearly 19 per cent. above the first.

It will be seen from the Table, that the Lackawanna coal, which, when pure, approximates sensibly towards the semi-anthracite in its physical structure, is not only light in the solid mass, but relatively bulky when broken.

The figures in the Table indicating the weight per cubic foot, of the Welsh coals, both anthracite and semi-bituminous, so far exceed those for the American coals of the same classes, and differ moreover so widely in their ratios to the corresponding specific gravities of the coals themselves when compared to the ratios of the cubic foot weights of the American coals to their specific gravities, that we are compelled to infer that the mode of estimating the cubic foot of lump coal by the British experimenters was essentially different from that adopted in this country by Professor Johnson and ourselves. In no other way can we account for the large disparity witnessed. This is so serious, considering the lightness, by specific gravity, of the Welsh specimens, that it will be safest not to attempt any comparison here between either the stowage of the corres-

ponding coals of the two countries, or between the rank they respectively hold in the order of their evaporative power for equal bulks, which includes the former as one of its elements.

The *third* important relationship of the coals to each other exhibited by the numbers in the Table, is that of their *composition*, as determined by proximate analysis, defining the proportions respectively, of the volatile combustible matter, the fixed carbon, and the earthy or incombustible residue. In this aspect, it will be seen that the four several classes of coals display a regular augmentation in the average per centage of the volatile combustible matter, this being about 3 1-2, 7 1-3, 13, and 30, in anthracites, semi-anthracites, semi-bituminous, and bituminous varieties respectively. The corresponding declension in the amount of the fixed carbon, is represented by the numbers 89 1-2, 84 1-4, 74 3-4, and 57 1-3; while the incombustible or earthy matter is in no established proportion or gradation, but varies with the individual coal seams, and even in fact with their different subdivisions. Nevertheless it will be noticed as a general feature, that the anthracites and semi-anthracites of the Table are decidedly purer than the two bituminous classes.

An analysis of a coal into its *ultimate* elements shows that its combustible matter, consisting of carbon, hydrogen, oxygen and nitrogen, embraces, except in the dryest anthracites, invariably a larger amount of carbon than is ever left in the form of coke when the volatilizable portions are distilled or burned away. The cause of this is, that a part of the gases are in chemical combination with a portion of the carbon, while another part, especially the hydrogen and oxygen, though probably in a free state in the pores of the coal, are ready at a low heat to seize upon another equivalent amount of the carbon, so that from both the sources, a greater or less proportion of the total carbon, depending on that of the gases, is burned in the gaseous form in the flame and smoke of the fire.

A *proximate analysis* of a coal by heat merely, separates, first, the free or uncombined water, varying from less than 1 to 3 or more per cent.; next, the whole of the combustible volatile matters, including the portion alluded to of the total carbon; then the fixed carbon of the coke, and as the final residue, the earthy ashes.

As the useful values of coals are variously influenced by the presence and nature of their volatile combustible part, it is expedient that I here notice the chief results of observation and experiments in relation to this ingredient.

One effect of a large excess of volatile matter in a coal, is to impair seriously its heating power. All the researches recorded in the Table, concur to prove this point. Comparing the average volatile combustible matter with the average weight of water evaporated from the temperature of 212 degrees by 1 lb. of coal of each of the four classes, the full bituminous kinds display an evaporating power of less than 8 lbs. to more than 9.5 lbs. for the other three varieties. Numerous elaborate researches go to show, that with very many samples of bituminous coals, the heating effect of the whole volatile portion of the fuel is almost "absolutely negative," and it has even come to be a prevailing opinion, that the total evaporative efficacy of a bituminous coal is no greater than that of the coke or fixed carbon which it contains. Certain it is, that in the ordinary way of practice with the boiler furnaces in use, the absolute equivalent of heat belonging to the coke, (all of which is not procurable, however,) exceeds considerably, with rare exceptions, that which is actually produced by experiment on the original coal. Some authorities, among them Professor W. R. Johnson, have evolved results which seem to indicate that the heating efficacy of a coal is measured by that of the whole of its carbon rather than by that of its coke, which is but a portion, and general experience would appear to sustain this relationship. We must keep carefully in view, however, that such a proportion is liable to be constantly departed from, through

imperfections in the furnaces constructed for bituminous coals, and that moreover the deviation from this or any other fixed ratio, will vary with the variable nature of the bituminous compounds which different coals contain.

The special qualities of the different bituminous and semi-bituminous coals, are not caused solely by the proportions of the volatile matter they contain, but are as intimately connected with their chemical constitution. A most important practical distinction in coals, is that between the caking and the open-burning varieties; and upon these characters, even more than upon their mere amount of bituminous matter, depend their adaptations to many economical uses. For the manufacture of coke, and the production of a hollow forge fire,—where this is needed,—the melting coals are valuable, but where a very active combustion is demanded, the open-burning kinds are preferable, since, by not fusing but only partially swelling, they afford a freer passage to the oxygen and give out a higher heat. A comparison of the analyses of coals, with the observations upon their manner of burning, shows clearly, that, except within certain limits, the proportion, simply of bituminous matter, has little to do with their free-burning or their caking qualities. As a general rule, the small amount of combustible volatile matter in the semi-bituminous coals, is associated with the absence of any marked tendency to cake into a close or hollow fire; but among the true bituminous class this tendency appears to bear no relation to the degree of bituminization, some of the dryest of these having not more than twenty-five per cent. of volatile matter in all, being decidedly fusible and close-burning, while there are others with not less than forty-five per cent., which burn with a free open fire.

It would appear "that the property of caking generally, increases with the quantity of hydrogen and oxygen in the coal, and especially with that of the hydrogen," yet to this rule there are found some striking exceptions; and we are compelled in considering all the phenomena, to refer the

different tendencies in various coals to soften and cake, to the existence of different kinds of bitumen, or at least to differences in the constitution of the coals as respects the mode in which the gases are combined with the carbon. This is a subject of much practical and scientific interest, and one which calls for further investigation at the hands of chemists.

A review of all that has been done in relation to this question of the effect of the volatile matter, seems to justify this general statement, that the evaporative power of a coal never exceeds in practice that due to its whole amount of carbon, and is oftentimes as low as that procurable from its coke alone; while the extent to which it falls short by imperfect combustion, of that fullest attainable measure of efficiency, is greater in proportion as the coal is more bituminous. The cause of the waste of so much power in the combustion of bituminous coals, notwithstanding the intense temperature developed by the gaseous products while burning, is clearly to be ascribed to the amount of heat absorbed in raising the cold fuel to the point of ignition, and the yet larger portion made latent by the change of the volatile portions from the solid to the gaseous condition, while only a part of the heat of their combustion is returned. Unless burned with a very intense heat, and with a large excess of atmospheric air, a part of the carbon of the coal passes to the chimney in the form of carbonic oxide gas, having but half undergone combustion, or having given out but half of its possible full product of heat. At the higher temperature evolved by the dryer coals, a more total combustion takes place with the immediate production of carbonic acid, and the entire amount of heat produced by oxygen and carbon is developed.

It must not be inferred from what has now been said, that every amount of volatile matter in a coal, whether much or little, must necessarily impair its heating power. The whole tenor of the researches made would seem to contradict this, and to show that the possession of a certain

proportion, within restricted limits, exalts not merely the activity or speed of the combustion, but the total heating power, as measured by the evaporative effect. Thus it appears that both the semi-anthracites and the dryer semi-bituminous coals, when they are properly burned, rather surpass, in calorific energy, the class of the hard anthracites. A small share of the easily combustible volatile gaseous matter seems very useful, by promptly kindling the solid carbon, with which it is in contact, and thus enabling the fuel to dispense with so vast a current of cooling air, as it is demanded for the full ignition of a dry refractry anthracite. But to confer on a coal the highest heating efficacy, experience and practice would suggest, that the proportion of gaseous matter in it should be no more than just enough to facilitate the kindling of the freshly supplied portions, by quickly transmitting its own combustion to the other parts, but not so large as to occasion any sensible waste of power. It is therefore, as adding to their activity, without impairing their strength, that we regard as so important, the presence of the trivial quantity of free burning gases in the Zerbe's Run and other semi-anthracites.

Another class of ingredients in coal, the proportions and qualities of which are equally influential with those of the gaseous products, are the earthy matters. These, like the volatile constituents, are somewhat variable in their nature, and by the forms they take under different intensities of combustion, much affect the efficiency of the coals to which they belong. Being differently fusible themselves, and affecting differently the fusion of each other, no two of the earths, alkalies, or metallic oxides, of the ashes, but differ in their agency when subjected to an elevated heat, and their mutual reactions are moreover changed, as the temperatures are changed, to which they are exposed. It hence arises, that the residue from many coals, melt, to a large extent, under no very intense combustion, into various descriptions of hard semi-vitreous slags; others yield a less stony clinker, and some again, at a far more

elevated heat, result only in a partially agglutinated spongy, open cinder, or even in a pulverulent or flaky ash. There are perhaps no coals, whose ashes, when exposed to the extremest heats procurable by artificial blasts, will not soften to a cohering cinder, or even melt in part into a stony clinker; but as the tendencies to these several degrees of fusion are very various, it proves to be a distinction affecting the practical value of coals, which is of the utmost importance. In domestic consumption, where the heat of combustion is comparatively moderate, the quantity, rather than the quality or fusibility of the ashes, is the point of most consideration; but where an excessive and melting heat is required, as in many modes of generating steam, the practicability of employing a coal at all, will oftentimes be determined by this one quality of the clinkering of the ashes. In all such circumstances, those coals are best, the ashes of which are of a nearly pure white, and which, with large amounts of silica and alumina in their composition, contain little or no alkali, nor any lime nor oxide of iron. Of this character are the earthy residuæ of the best white-ash anthracites of Pennsylvania, and, in an eminent degree, the ashes of the Zerbe's Run semi-anthracite.

The two columns G and J in the Table, relating, the one to the per centage of clinker alone, the other to the per centage of the total waste including clinker ashes and fine particles of intermingled unburned coal, are instructive in this connection, in several points of view, in disclosing, first, the different proportions of residue from different coals; secondly, the varying ratios for the different classes of coals, of the clinker formed, to the total waste, and of both of these to the actual amount of earthy matter; and again, the marked influence of an increased intensity of combustion by strong mechanical blast, in increasing where the coals are of the same class, and of equal purity, both the quantity of clinker and of total waste.

It will be noticed, that the hard white-ash anthracites of Pennsylvania, all the samples of which, experimented on by Professor Johnson, appear to have been of, at least, full average purity, exhibit not more than fifty per cent. of additional waste beyond the total quantity of earthy matter detected in them by chemical analysis, and not more than one eighth of the total waste, in the form of clinker, while the Mount Laffy coal, investigated by ourselves, displays a waste very nearly double the actual amont of earthy matter, and a proportion of clinker, to the entire waste of fully two thirds. The reason for this important difference is obviously to be found in the dissimilar conditions of the combustion. The apparatus employed by Prof. Johnson had only that activity of draught which could be supplied by a chimney 45 feet high, while the furnaces beneath our boilers, besides connecting with a tall chimney stack, were artificially supplied with air by a powerful fan, 30 inches in diameter, driven at a speed of 480 revolutions per minute. In the one case, the heat was barely enough to fuse a small part of the ashes; in the other, it was so energetic as to melt two thirds of the total quantity, and to augment the weight of the clinker formed, by inclosing unburned fragments of coal, to the amount of several per cent.

The effect of the same extreme degree of heat, was witnessed on the ashes of the coal from Zerbe's Run, but to a less extent, from its greater infusibility. The total waste from this coal was an average almost twice the absolute amount of earthy matter, but the clinker was between a third and a fourth part only of this total waste. In the case of the Rhode Island coal, a higher fusibility in the ashes, due to the presence of lime and other fluxing ingredients, resulted in the conversion of almost the whole of the waste matter into clinker.

In other trials, less systematically conducted, and not here recorded, the coal of the Zerbe's Run estate, when burned without a blower, but with an ordinarily strong

draught under steam boilers, produced almost no true clinker at all, but merely a small proportion of loosely cemented crumbly cinder, the rest being dry pulverulent ashes.

Directing our attention for a moment, to the clinker and waste from the semi-bituminous and bituminous coals, we perceive, that while the ratio of the total waste to the earthy matter in the coal, is very nearly what it appears in the anthracites, the proportion of clinker or fused matter to the whole residuum, is, notwithstanding the far milder heat employed, nearly or fully as great as that from the coal of Zerbe's Run, burned under the strongest blast.

The explanation of this greater tendency in all these bituminous coals, compared with the anthracitic, to form clinker when exposed to the same heat, is to be detected in the different constitution of their ashes — the Pennsylvania Anthracitic Basins containing remarkably little lime, or other fluxing earths or alkalies, either in the substance of their coals or in the strata which imbed them; whereas it so occurs, that an influential quantity of one or more of those fusible ingredients appears in the ashes of almost all the fuels of the bituminous groups, as well those of the Dauphin and the Cumberland Basins, as those of the Richmond, the Trans-Allegheny, and the British coal fields. In the ashes of the anthracites, the proportion of lime rarely surpasses 2 per cent., while in those of many of the bituminous coals it exceeds 5 or 6 per cent.

A *fourth* property of fuels, upon which their value, for certain leading and rapidly extending applications in a large degree depends, is that of kindling rapidly, and burning with great celerity when required. This quality in coal now enters as a large element in the conditions which control, through the agency of steam, the speed of commerce and the facilities of human intercourse, and which are enriching all the resources of civilized life, by daily increasing conquests over time and space. To it, therefore, even more earnestly than to the mere absolute heating energy of

different fuels, must the researches of practical science henceforth be directed. An enormous amount of yet unawakened speed, as well as strength, still slumbers in certain forms of coal — the most condensed and the most tractable material shape in which a gigantic mechanical power is stored away. Only a portion of either of these has hitherto been evoked by art, and it is of the utmost importance that every point connected with our fuels, or with the conditions under which they are burned, that promises to procure from them either increased activity or additional total heat, should be closely investigated.

The peculiarities of mechanical structure and of chemical constitution which are mainly influential in conferring on coals a high degree of combustible or evaporative activity, have been already stated, and it will suffice here merely to recount them. They are, chiefly, the absence of too extreme a density or cohesion; a certain medium amount of divisibility on the fire; a moderate proportion of combustible volatile matter, to quicken ignition and propagate the heat; the quality of keeping an open fire, and purity from much earthy matter, especially clinkering ashes.

The experimental results embodied in the Table, under the appropriate columns, express the relations of the various coals to each other in these respects. These, and the numbers in the two columns, K and O, giving the pounds of coal severally consumed per hour to each square foot of furnace grate, and the pounds of water evaporated per hour to the same amount of surface, embrace in one view both the elements which modify the rate of activity of the different fuels, and the rates themselves as ascertained by experiment.

Keeping in view what has been already carefully stated, of the superior energy of the draught used in the experiments made by ourselves upon the Mount Laffy and Zerbe's Run coals, over that employed upon all the other results, and making our comparisons only between those results which were procured under similar or comparable

conditions, we will be guided by the Table to some instructive conclusions.

Looking first at the combustible activity of the several classes of coals, as determined by the apparatus used by Prof. Johnson, we discern the fact that the rapidity with which they burn is greater as they are more bituminous, or contain more combustible volatile matter. Thus, the anthracites burn at the rate of 6.60 pounds per hour on each square foot of the grate, the semi-bituminous coals at the rate of nearly 7 pounds, and the full bituminous coals at the rate of more than 9 pounds. The Lykens Valley semi-anthracite shows a rate of 6.92 pounds; the semi-bituminous coals of the Dauphin Basin a rate of 6.86 pounds, and those of the Cumberland, 7.10 pounds, while the middle secondary bituminous coals of the James River Basin, in Virginia, display the greater rate of 7.41 pounds to the same surface.

Turning to the figures indicating the respective *times* required for getting the boiler into full action, we perceive that the differences in the rapidity of kindling are much more marked than those of the rates of sustained combustion; the periods being for the four classes of coals, 3.10, 2.63, 1.14, and 0.92 hours respectively.

Giving our attention, in the next place, to our own experiments upon the hard anthracite and the Zerbe's Run semi-anthracite, with an artificial blast, we notice two points for comparison; first, a strikingly greater activity in the combustion of the same kind of coal under a strong current, than under the gentle draught used by Johnson, in the ratio, for the anthracites, of 9.23 to 6.60; and secondly, a trivial superiority in this particular on the part of the semi-anthracites of Zerbe's Run, over the hard dry anthracite burned under like conditions. Under both rates of combustion, the semi-anthracites display a rather higher activity than the true anthracites — with the ordinary chimney draught a ratio of 6.92 to 6.60, and with the blower, one of 9.26 to 9.23, or by the longest and most

complete trial with strongest blast, a ratio of 10.20 pounds burned to precisely 10 pounds.

It is here especially worthy of remark, that a moderate force of draught through the fuel, seems to be that which is best suited to the fullest economical performance, speed and power both considered, of the semi-bituminous and bituminous coals, while a strong current is best adapted for the same ends to the anthracites.

The maximum heating effect from any coal, is procured when the air passes it fast enough to burn entirely all the combustible matter it can surrender to it, by its own heat; but when the current exceeds this rate, its influence is *counter-active*, cooling and quenching a portion of the burning matter, and driving it wastefully forward with the combustion not completed. The different ignitibility of the various classes of fuels, sets of course different limits to this point of economical rapidity of blast and of combustion; limits which are sooner passed with the bituminous than with the anthracite coals.

Bearing upon this topic, it should be noticed that, since we inevitably lose a portion of the whole heat procurable from a coal, when in our desire for speed or copiousness of combustion in a given time, we urge the fire too eagerly, we may perceive under what disadvantages the hard Mount Laffy anthracite and Zerbe's Run semi-anthracite were burned in our experiments, so far as mere evaporative economy is considered. Nothing speaks so strongly to the merits of both these coals, as pure and efficient fuels, than the fact, that the very high evaporative power indicated in column N of the Table, co-existed with a rate of combustion so manifestly wasteful of heat as that shown in the preceding column K under consideration.

Another, and as already intimated, a very essential quality in coals, affecting more perhaps than any other element their commercial value, is a *high absolute heating power.* This *fifth* principal relationship of the coals under comparison, will be seen numerically expressed in the General

Table, in column N, which shows the experimental effects of their combustion in pounds of water, evaporated from the standard temperature of 212°, by one pound of each kind of coal. After what has been already pointed out, on a previous page, respecting the unfavorably rapid rate of the combustion in our own experiments with the hard Mount Laffy anthracite and the coal of Zerbe's Run, little further need here be said in calling attention to the true relative evaporative power of the different classes and varieties of coals, than to suggest to the reader to make due allowance for that circumstance. Between the anthracites and the semi-bituminous coals, burned under the same conditions of draught, there is a trivial difference of effect in favor of the latter, attributable mainly to the superiority of one or two of the Cumberland samples; but comparing either class with the true bituminous coals, we perceive that those which take the lead in rate of burning, are far behind both the others in point of real efficiency. The pounds of water evaporated were 9.58, 9.66, and 7.96, for the anthracites, semi-bituminous, and full bituminous coals, respectively.

Regarding, in the next place, the results of our own experiments, we observe that the average performance of the excellent hard anthracite we tried was sensibly lower than the average work of the similar anthracites burned by Prof. Johnson with a gentler current; corroborating what we have alleged of the loss of evaporative economy from an over-active supply of air; but we perceive that notwithstanding the same important drawback on the full efficiency of the Zerbe's Run coal, the experiments demonstrated a decidedly superior evaporative power in the Zerbe's coal over the other, in the ratio of 9.58 pounds to 9.32 pounds of water to the one pound of coal. When the conditions were less unfavorable for economical results, the product in steam was respectively 10.60 and 10.19 to each pound of fuel. During this best experiment — as proved by the table presented by Dr. Hayes — the rate of combustion on the grate was, with the Zerbe's Run coal, as high as 10.20

pounds to the square foot per hour, while with the hard Mount Laffy anthracite it was 9.08 pounds.

This brings us to a review of the results shown in the next column, O, of the Table. This series of numbers, denoting the relations of the coals in their two important qualities of rate of burning, and evaporating effect from equal weights, or, in other words, their *activity* and their *strength*, expresses more justly than any other portion of the Table, the relative practical values of the several coals. It will here be seen that the anthracites, semi-bituminous, and bituminous coals, burned in the same apparatus, and under conditions best adapted to the two latter classes, display evaporative rates in the ratios of 62.93, 67.46, and 70.92 pounds of steam per hour, to each square foot of grate.

Reducing our own results, to the same units of time and surface, we notice that the hard anthracite produced as much as 85.96 pounds while the semi-anthracite of Zerbe's Run went even beyond it in the proportion of 88.71 pounds, both of which are certainly very enormous products. But these which are only averages, were much exceeded in the best states of working, when after the middle of the week, the flues being all fully heated, the very copious blast employed was attended by a rather less than usual waste of fuel. At those times the highest activity and heating power united, yielded in steam, the really enormous product of 91.52 pounds from the hard anthracite, and 108.10 pounds from the semi-anthracite of Zerbe's Run.

In approaching the conclusion of this portion of our subject, — the relative efficiency of the various coals in generating steam, — we arrive finally at a comparison of the fuels in their three several aspects of evaporative activity, absolute heating power, and capacity of stowage combined. In other words, we have now to ascertain in what order the several varieties and classes range themselves, when each is estimated according to the degree in which it unites the three primary qualities of speed, strength and compactness.

The column P, the last in the Table, derived from multiplying together the three ratios expressing the pounds of coal burned on each square foot of grate per hour; the pounds of steam produced to each pound of coal burned; and the pounds of coal containable in each cubic foot of space, exhibits for the several coals their relative total values compounded of all these elements.

The Table here speaks for it itself. The numerical aggregates denoting the rank of the anthracites, the semi-bituminous coals and the full bituminous coals, are respectively expressed by 3349.8, 3496.4, and 3462.3 pounds of water evaporated each hour, on each square foot of furnace grate by each cubic foot of broken coal. It thus appears that the semi-bituminous surpass, somewhat, the bituminous coals, and that these exceed the true anthracites.

The relative rank of the hard anthracite of Mount Laffy, compared with the semi-anthracite of Zerbe's Run, is indicated by the ratio of the numbers 4598.8 to 4635.1, which denote the relative efficiency of each for marine navigation.

It will not be correct, of course, to compare these high results last recorded, critically, with the first series, since, as we have several times stated, the data included in them were procured from experiments differently arranged as to the rates of combustion. Yet, if we will keep in view the fact, that the strong current with which we blew our fires, was probably as inimical to a large evaporative result, per pound of coal, as it was friendly to an increased speed of combustion, the conclusion becomes very manifest, that the numbers in the Table cannot be far astray in denoting the relative values of the coals reviewed in their triple aspect of combined *activity*, *strength* and *portability*.

Having in the foregoing pages disposed of the various topics connected with the value of the several kinds of coal, in their applications to the production of steam, and with the merits of the Zerbe's Run semi-anthracites for that important use, it remains for me to add a few concluding

remarks on the suitableness of this particular variety to the smelting and working of iron.

It is well known that purity in the fuel is a most important element of economy in the process of iron smelting. A difference of only 5 or 7 per cent. in the quantity of earthy matter in two coals is the source of a serious difference in the final cost which they involve. Not only must an extra amount of coal be introduced into the furnace to supply the deficiency caused by the additional impurities, but a still further portion is needed to melt the excess of ashes in the whole body of the fuel. The increased quantity of earthy matter difficult of fusion, thus supplied, calls for a proportionate increase in the limestone or flux, which itself again exacts a certain amount of fuel to melt it with the additional ashes. Thus from the one cause we require to make a triple augmentation to the fuel. If the ore employed be of a fair degree of purity, the surplus foreign matter, ashes and flux together, made thus to burden the furnace, will materially exceed 5 or 7 per cent. of the total amount of earthy matter originally there, and we therefore perceive that a seemingly trivial difference in the coals may prove a really important difference in the results. But besides these sources of extra cost, there are others which flow in their train. Among these are the items of expense for labor, entailed by handling the additional fuel and flux, and the increased cinder from the furnace, and the more indirect loss from the lessened product which the furnace yields in a given time.

But the quality or nature of the extraneous matter has even a greater influence than the quantity, upon the fitness of a fuel for the purposes of smelting. Of all the substances of a hurtful kind, commonly to be found in coals, *sulphur*, usually combined with iron, forming minutely disseminated sulphuret of iron, is by far the most injurious. The proportions in which it prevails in different coals, are very various, many beds revealing scarcely a trace, while others again contain as much as 3 or 4, or even 6 per cent.

of this deleterious constituent. As a general fact, the anthracites and semi-anthracites are decidedly more free from sulphur than are either the semi-bituminous or the fully bituminous coals.

The better kinds of the two first named classes exhibit, as the Table proves, but insignificant traces of it, not more in the *average* than 0.05 per cent. or one part in 2000 of the coal. The semi-anthracites, on the contrary, display an average proportion of more than 10 times as much as 0.53 per cent., while the mean amount for the three groups of bituminous coal there presented is materially greater still, being as much as 0.61 per cent., or one part in every 164 parts of the coal. The Zerbe's Run semi-anthracite has disclosed not a trace of this substance, either in the mines or in any of the samples burned or critically analyzed.

Upon the view which I have advocated in the early part of this essay, that the anthracite coals are true *solidified cokes*, or the de-bituminized forms of the ordinary gaseous coals, the reason for their comparative exemption from sulphur is obvious and natural. The same highly heated volcanic steam, which in issuing through the strata baked and metamorphosed the soft clays into indurated slates, and distilled out from the bituminous coal beds their volatile bitumen and gases, would, by a well known and often practised chemical reaction, carry off the sulphur. By a process more refined and admirable, than any which man can hope to imitate, these matchless varieties of coal have been ages ago de-sulphuretted, coked, and compactly pressed. They are the fuel of the world in its most elaborated, purified and perfected form; fine enough for any of the most delicate behests of chemistry, yet strong enough to achieve, with the aid of mechanism, the wildest and most daring dreams of speed and of physical power, which the genius of invention can conceive.

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